LBL-18134

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

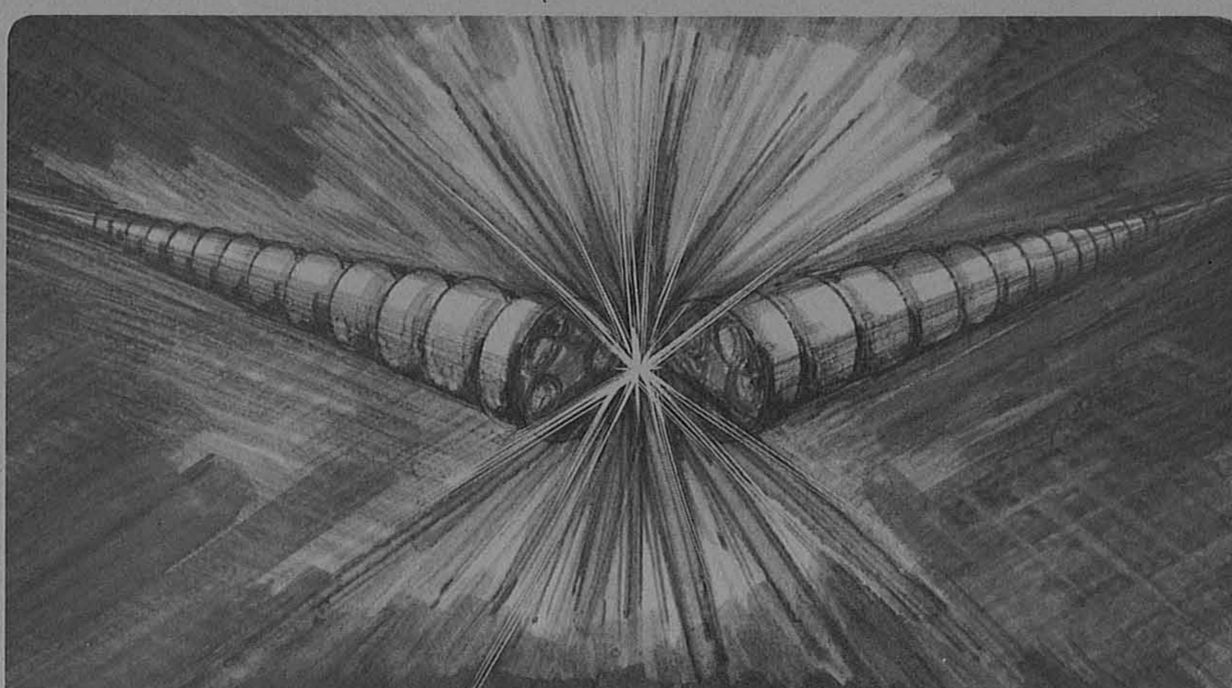
Accelerator & Fusion Research Division

Presented at the 10th International Cryogenic Engineering Conference, Helsinki, Finland, July 29 - August 4, 1984

HEAT TRANSFER THROUGH He II IN A 9.6 m LONG 35 mm ID TUBE

S. Caspi and R.V. Schafer

July 1984



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-18134
SSC-MAG Note-16

HEAT TRANSFER THROUGH He II IN A 9.6 m LONG 35 mm ID TUBE*

S. Caspi and R. V. Schafer

July 1984

Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

HEAT TRANSFER THROUGH He II IN A 9.6 m LONG 35 mm ID TUBE*

S. Caspi and R. V. Schafer

Lawrence Berkeley Laboratory, University of California, USA

The limiting heat flux at the onset of He I was measured in a 9.6 m long tube of 35 mm ID at a bath temperature between 1.8 K and T_λ and a pressure of 1 atm. The measured limiting heat flux during axial heating is 50% more than end heating at the same bath temperature. Both cases agrees with the Gorter-Mellink mutual friction theory.

INTRODUCTION

The use of superfluid for cooling superconducting magnets has proven useful, manageable and operational. The increase in magnet stability even for high current density magnets is in agreement with the excellent thermal properties of He II. It is however the lower bath temperature of superfluid where the true potential of its use lies. With the increase in J_c of NbTi cables at 1.8 K, 25% less superconductor is required to arrive at the same magnetic field as for 4.2 K. In large systems such as the proposed Superconducting Super Collider such a cost saving is of major proportions (several $100 million). This possibility had recently been discussed in a workshop on "Cryogenics for the SSC" held at BNL.

On the topic of heat transfer to superfluid Helium in long tubes, it was felt that a need exists for an experiment, in scale with current He I technology. Past experience with heat transfer in long tubes[1,2] (10 to 100 meters long) was confined to tube diameters of less than 1 cm. The LBL He II magnet test facility was used to test a tube of a cross section area which is an order of magnitude larger than any tube previously tested.

EXPERIMENTAL SETUP

The tube, 304 stainless 35.5 mm ID 1.3 mm wall, was assembled from 8 long pieces varying in length from 860 mm to 1080 mm. The sections were placed side by side and interconnected (26 welds) to form a spiral continuous tube 9600 mm long of a rectangular shape 324 x 1195 mm, Fig. 1. Along the tube temperature sensors (carbon glass from Lake Shore Cryotronics) were placed into copper nipples which were soldered into the tube to 1/3 diameter length. One end of the tube was plugged and a 200 Ω Manganin heater wire was attached to a copper block next to it (end heater). In

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

order to introduce a second heater, (axial heater) the tube was first copper plated and then 4 copper strips 3.2x1.6 mm were soldered along it at 45 degree angles with respect to each other. In the strips a groove was made to accommodate 2 layers of heater wire (Manganin 0.2 mm diameter) which were held in place with the aid of fishing line and Stycast epoxy. The wires were connected to a bus to form a 158 Ω heater. A four wire measuring technique was used to measure both the heaters and temperature sensors resistance.

The tube was placed inside a 375 mm ID 1290 mm long cryostat with the tube free end pushed through and welded at its bottom. NEMA G10 guards were placed between the cryostat walls and the tube to keep it straight. This anticryostat was then placed into the existing horizontal test facility cryostat with both units connected and glued along their flanges. In this fashion He II at 1 atm pressure filled the annulus space between the cryostats, and with the anticryostat evacuated the tube was left in a heat leak free cavity. All sensor wires were hooked up to a data acquisition system driven by a HP 1000 computer.

THEORY

At zero net mass flow, when a steady state counter flow is established along a He II filled heated tube, a temperature gradient will reflect mutual interaction. By increasing the rate of heating the temperature at the warm end will rise until the Lambda temperature is reached. This establishes the maximum rate of heating Q_λ for a tube of a given length before part of it undergoes the transition to He I.

(a) Tube heated at one end

The relationship between the heat flux density, the tube length and the temperature difference is based on the Gorter-Mellink mutual friction relation. For a tube heated at one end this relation has been written empirically in two forms.[3,4,5]

$$q_\lambda \, L^{1/3.4} = Z(T_b) \tag{1}$$

$$q_\lambda \, L^{1/3} = K_{gm} \, f(T_\lambda) \, G(T_b/T_\lambda) \tag{2}$$

where T_λ, T_b = the Lambda and bath temperatures, q_λ = the "limiting heat flux density" (w/cm^2); L = tube length (cm); $Z(T_b)$ = integrated conductivity function between T_b and T_λ to the power of (1/3.4); K_{gm} = Gorter-Mellink constant; $f(T_\lambda)$ and $G(T_b/T_\lambda)$ are integrated functions of He II properties.

$$Z(T_b) = -28.96\, T_b^2 + 98.57\, T_b - 77.86 \qquad 1.8 < T_b < T_\lambda$$

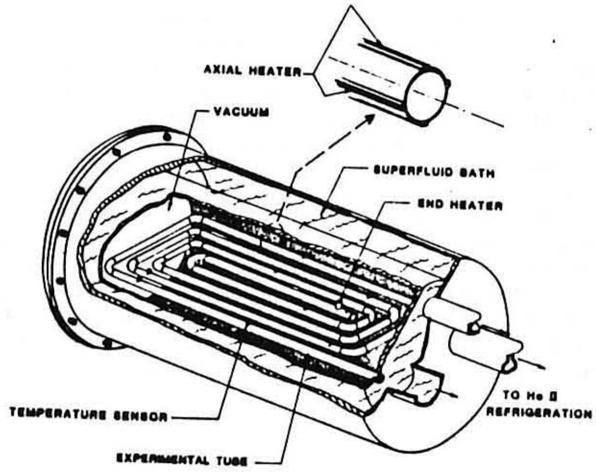
A polynomial has been curve fitted to the function $Z(T_b)$ of Ref. 3.

(b) Tube heated axially

When a tube is heated axially at a constant rate per unit length the integration of the Gorter-Mellink relation, Eq. 1, results in[6]:

$$q_\lambda \, L^{1/3.4} = 1.546\, Z(T_b) \tag{3}$$

where q_λ is the total heat flux density at the cold end of the tube. The number 1.546 corresponds to $(3.4+1)^{1/3.4}$.



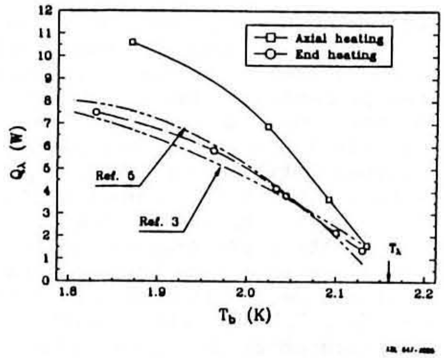
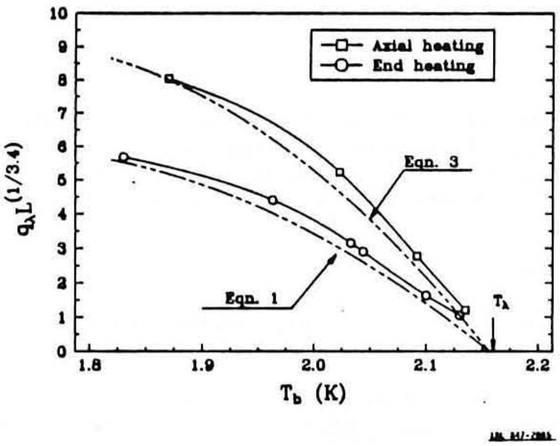


Figure 2 Limiting heat flux during end and axial heating.

Figure 1 Experimental tube in cryostat.

Figure 3 Correlation of limiting heat flux density and tube length as a function of bath temperature.



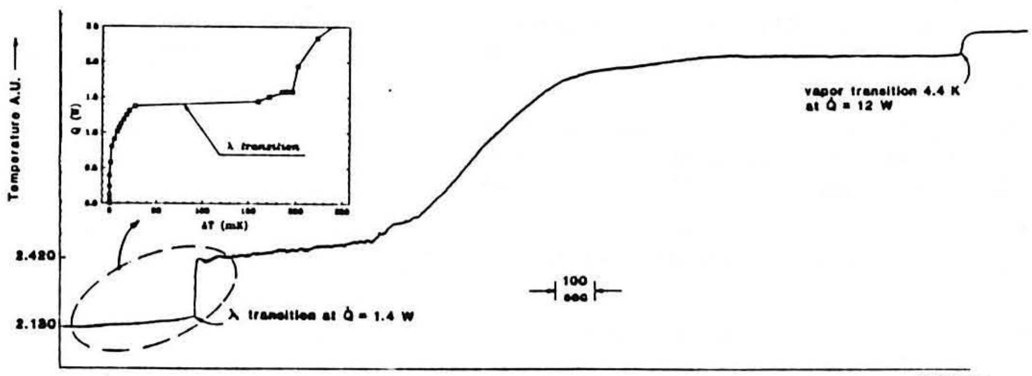


Figure 4 Temperature versus time at the warm end of the tube duirng a steady heat increase in the end heater. Insert shows the Lambda transition as heat flux versus ΔT.

RESULTS

During preliminary tests we measured the time response, of the temperature sensors, to a step heat input of several watts to range between 2 and 5 minutes. This established a time scale for which no change in temperature indicated steady state. We then proceeded to measure the limiting heat flux Q_λ by incrementally increasing the heat input Q until the transition to He I occurred at the warm end. The power was then incrementally decreased until He II has been recovered. This process was repeated until a heat flux Q_λ was reached where an increase of 0.1 to 0.2 W would result in the transition to He I. The limiting heat flux and limiting heat flux density as a function of T_b are plotted in Figs. 2,3 for both end and axial heating and compared with expected values. Deviations from the theoretical values are noted for bath temperatures close to T_λ. Once He I has been generated He II and He I will coexist. Increasing the end heater power from 1.4 W to 12 W, for $T_b = 2.13$ K, will result in a phase change to vapor at the tube end, Fig. 4. This coresponds to a heat flux density of 1.2 w/cm^2 in accordance with the film boiling heat flux density of subcooled He I at $T = T_\lambda$ and 1 atm pressure.[7]

CONCLUSIONS

For a He II tube of 9.9 cm^2 cross section area, the values of the limiting heat flux are consistent with those of tubes with cross section area of less than 1 cm^2. The limiting heat flux for a tube heated axially is 50% larger in according with the integrated GM relation. The data show no direct evidence that the tube elbows effect the limiting heat flux values.

ACKNOWLEDGEMENTS

We gratefully acknowledge the dedication, support, and encouragement of J. Rechen, M. Helm, and W. Gilbert during the course of this experiment. We also wish to thank D. Kemp for his help and patience. Last but not least we thank C. Taylor for his recognition and support of this work.

REFERENCES

1 Lottin J.C. 'He II experimental facilities at Saclay'. Adv. Cryo. Engr., vol. 27, 1981, pp. 431-439.

2 Van Sciver, S.W. and Christianson, O. 'Heat tranport in a long tube of He II.' 7th Inter. Cryo. Engr. Conf. 1978, pp. 228-234.

3 Bon Mardion, G., Claudet, G. and Seyfert, P. 'Practical data on steady state heat transport in superfluid helium at atmospheric pressure'. Cryogenics, vol. 19, 1979, pp. 45-47.

4 Kamioka, Y., Lee, J.M. and Frederking, T.H.K. 'The Gorter-Mellink constant associated with counterflow convection in pressurized superfluid He II (He 4)'. 9th Inter. Cryo. Engr. Conf. 1982, pp. 283-286.

5 Kamioka, Y. 'The prediction of steady state heat flux and related temperature profiles in pressurized superfluid He II'. Cryogenics, vol. 23, 1983, pp. 367-372.

6 Warren, R. 'He II cryogenics system, first cut'. Lawrence Berkeley Lab. Engr. Note M5330, 1979.

7 Caspi, S. 'Heat transfer to subcooled He I'. Adv. Cryo. Engr., vol. 29, 1983, pp. 281-287.